ARM TR-075

Broadband Heating Rate Profile (BBHRP)

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1. Introduction

The main objective of the ARM Broadband Heating Rate Profile (BBHRP) project is the creation of a long-term dataset of computed vertical radiative heating rate profiles for all ARM Climate Research Facilities (ACRFs). The accuracy of these heating rates will be established by extensive comparisons of corresponding computations of surface and top-of-atmosphere irradiances with radiometric measurements at the ACRFs. This effort is designed to build upon and broaden the fruitful long-standing series of measurement-model comparisons of clear-sky longwave surface radiation at the SGP ACRF (Turner et al. 2003; Brown et al. 1997).

The specific objectives of the BBHRP project are to:

- Compute heating rate profiles for all ACRFs based on in-situ measurements and using a validated radiative transfer model

- Extend existing measurement-model closure studies to irradiance comparisons involving:
  - shortwave spectral region
  - top-of-the-atmosphere (TOA) fluxes
  - cloudy conditions
  - the spatial and temporal scale corresponding to a GCM “grid cell”
  - all ACRFs

- Generate datasets of measured and modeled radiation for both “soda straw” and grid-cell domains at the ACRFs

- Provide a “test suite” for researchers evaluating new parameterizations and data sources

This effort involves computing radiative heating rates and performing radiative closure analyses on two spatial/temporal scales, each corresponding to distinct input and output streams. First, a dataset likened to a “soda straw,” i.e., a narrow column centered at the Central Facility at the ACRF and distinct moments in time, has been developed; it is referred to as the “instantaneous” product, and its input profiles and associated products are termed “P_i.” The second dataset corresponds to the size of GCM grid cell and a longer-term (i.e., one-hour) time average, and will be utilized for studies involving Single Column Models. This dataset is referred to as “average,” and its input profiles and products are termed “P_a.”

The methodology used in the BBHRP project involves using radiative closure to evaluate potential improvements to the input streams or radiative transfer code: analysis of the statistics of the residuals of the model calculations with respect to radiometric measurements at the surface and TOA indicates which data source, retrieval, etc. is of the greatest quality and should be utilized in the reference version of BBHRP. The vast majority of the inputs, which are based on in-situ measurements, have been evaluated in this way, resulting in the production of radiative heating rate profiles that are viewed with confidence.

The extensive objectives of the BBHRP project necessitate that it is a collaborative effort of all the Working Groups within ARM. An ARM Focus Group has been formed to provide a structure for the development and analysis associated with this project. The input and output streams, as well as documentation, for selected recent versions of BBHRP are available as an ARM PI data product at http://iop.archive.arm.gov/armiop/0pi-data/mlawer/. Similar material for all BBHRP versions are available at the http://engineering.arm.gov/~shippert/BBHRP/index.html.

Figure 1 provides a schematic overview of the BBHRP project. The initial step is the specification of atmospheric properties relevant to radiation by the appropriate ARM Working Group (e.g., aerosol radiative properties by the Aerosol Working Group). These properties are input into the radiative transfer model RRTM (Mlawer et al. 1997; Mlawer et al. 1998), which computes fluxes and heating rates. Comparisons are performed between the computed fluxes and measurements by surface broadband radiometers and satellite-based instruments. The differences between measurements and model calculations are then analyzed to determine the source of any issues, and this knowledge exploited to make improvements in data sources, retrieval algorithms, and the radiation codes. The computed heating rates are available for use in cloud modeling simulations and other investigations.

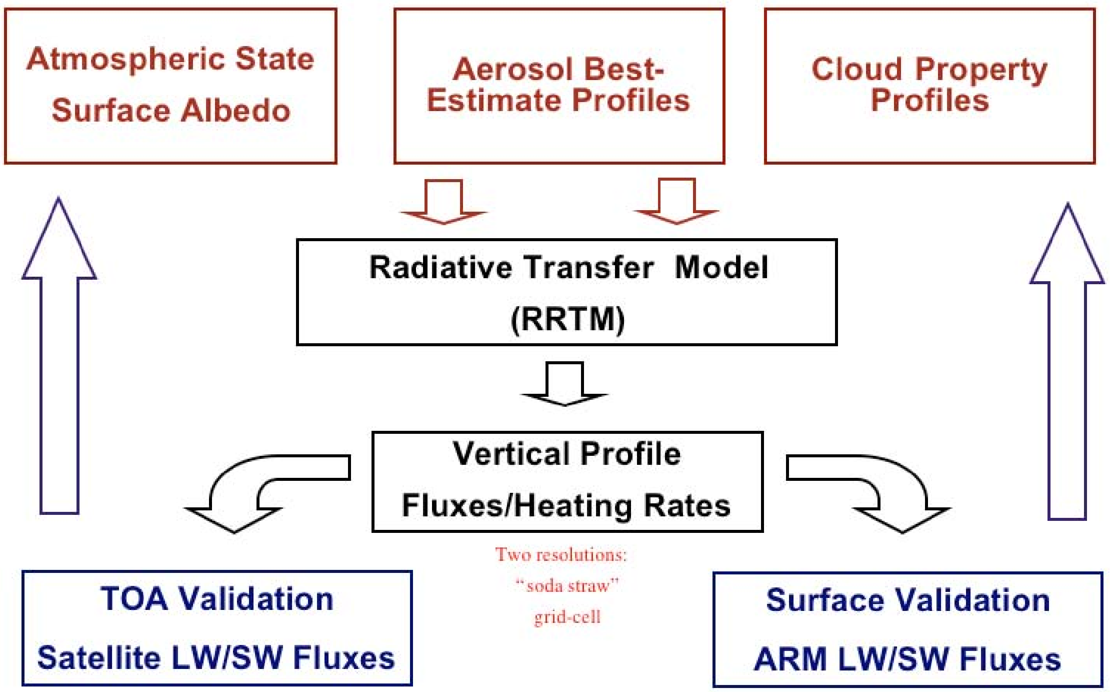

Figure 1. Schematic overview of the BBHRP Project.

2. Inputs to BBHRP

The following is a short description of the input data sources, retrieval algorithms, and radiation codes used in BBHRP for the SGP ACRF:

Radiometric Measurements -The longwave and shortwave surface irradiance measurements utilized in the P_i comparisons are 5-minute averages of the irradiance values provided by ARM Best Estimate Radiative Flux Value Added Product. The 5minute averaging window is centered at the time provided for each case. The measurement-based irradiance values utilized for comparisons at the top of the atmosphere (TOA) are from satellite-based instruments such as GOES and CERES. The TOA observations used for closure analysis are those measured in closest proximity to the Central Facility of the SGP ARM Climate Research Facility (ACRF) and temporally closest to the time provided for each case.

Radiative Transfer Models -The radiative transfer calculations are performed by the models RRTM_LW and RRTM_SW. Scattering calculations are performed in RRTM_SW using DISORT with 8 streams. The optical properties of liquid clouds are implemented in RRTM based on the parameterization of Hu and Stamnes (1993), while the ice cloud optical properties are from Fu (1996) and Fu et al. (1998). Maximum-random cloud overlap is assumed.

Atmospheric Profiles -Profiles of temperature and molecular abundances are determined by the same approach used in the AERI/LBLRTM Quality Measurement Experiment(Turner et al. 2004). The radiosonde observations of temperature and humidity are input into the atmospheric module of RRTM, which computes average temperatures and integrated water vapor column amounts for each layer. For clear vertical domains, the layer thicknesses range from 54 m at the surface to 4 km at the top of the atmosphere. If clouds are present in a vertical domain, the layer thicknesses change to 62.5 m between 375 m and 1 km and 100 m above 1 km. The column amounts of radiatively important molecules are determined as follows:

> Water vapor – each layer column amount from the sonde measurement is scaled by the ratio of the total precipitable water vapor retrieved from microwave radiometer (MWR) measurements and the total precipitable water vapor from the sonde (Clough et al. 1999).
>
> Carbon dioxide – a mixing ratio of 360 ppmv is used for the year 2000 calculations.
>
> Ozone – the relative values of the layer column amounts are consistent with the mixing ratios in the U.S. Standard atmosphere, but the total ozone column amount is scaled to agree with that measured by the Total Ozone Mapping Spectrometer (TOMS).
>
> All other species – mixing ratios are consistent with those in the U.S. Standard atmosphere.

Cloud Properties – The cloud properties used in the calculation are based upon the Active Remote Sensing of CLouds (ARSCL) value-added product (Clothiaux et al. 2000), which produces height distributions of hydrometeor reflectivity (and cloud boundaries)every 10 seconds based on observations from a Millimeter Cloud Radar (MMCR), Micropulse Lidar (MPL), and Laser Ceilometer. These ARSCL products are combined with thermodynamic profiles from radiosondes and column integrated water vapor estimates from a Microwave Radiometer (MWR) and input into the Microbase cloud property retrieval (Miller and Johnson 2002), which computes a time-height grid of the liquid water concentration, liquid effective radius, ice water concentration, and ice effective radius. Within the Microbase retrieval, the initial liquid water concentration data are integrated to produce an estimate of the Liquid Water Path (LWP). A ratio between this estimate and a retrieved value of LWP from a coincident measurement from a MWR is computed. Each value in the initial Microbase liquid water concentration profile is linearly scaled using this ratio so as to make the Microbase total LWP for each profile consistent with the measured value from the MWR. The retrieved cloud properties for each time and height are averaged over a 20-minute interval and the cloud fraction, LWP, particle effective radius, ice water path, and particle effective radius are computed. A 20 minute averaging interval is used because it is was empirically determined to be a reasonable time period over which the cloud properties retrieved by Microbase (appropriate for directly overhead) best represent the cloud fields affecting the “instantaneous” irradiance measurements.

Aerosol properties – The measurement sources from which the aerosol properties are derived depend on whether the case is classified as clear or cloudy. If it is clear, the aerosol optical depths are derived from measurements of the Multi-Filter Rotating Shadowband Radiometer (MFRSR). These aerosol optical depths, averaged over 5minutes, are used to derive an Angstrom relation which is used in the calculation. The aerosol single-scattering albedo is retrieved from the diffuse-to-direct ratio measured in two visible MFRSR channels. The aerosol asymmetry parameter is derived from measurements of the backscattered radiation by the surface-based Aerosol Observation System (AOS), which are adjusted to ambient humidity at the surface. If the case is cloudy, all aerosol properties are obtained from the Aerosol Best Estimate VAP (ABE).

Surface properties – The shortwave surface albedo values used in the calculation are based upon measurements of the upward-looking MFRSR and the downward-looking MFR, which are colocated at the 10 m and 25 m towers at the SGP CART site. For each location, the ratio of observed upward to downward irradiance in six measurement channels of the instrument are used to classify the surface type under that tower. This classification is then used along with the measured ratios to determine the surface albedo value appropriate for each band of RRTM_SW. The surface albedo values associated with the two towers are then averaged to obtain final surface albedos that are input to the model. The longwave surface temperature is inferred (assuming the surface emissivity is unity) from the measured upwelling longwave surface irradiance.

3. Results

An example of the heating rate profiles computed by the BBHRP methodology is shown below for March 3, 2000. As shown in Figure 2, the atmospheric conditions above the SGP ACRF on that day consisted primarily of multi-layered mixed-phase clouds, although at times certain layers contained just liquid or ice. Figure 3 shows the vertical heating rates for that day, which are governed by the presence and structure of the clouds. For this day, it can be seen that the liquid clouds generally have a greater effect on the heating rates than do the ice clouds, although there are times (e.g., 2300-0000 Z) for which the ice clouds have a significant effect.

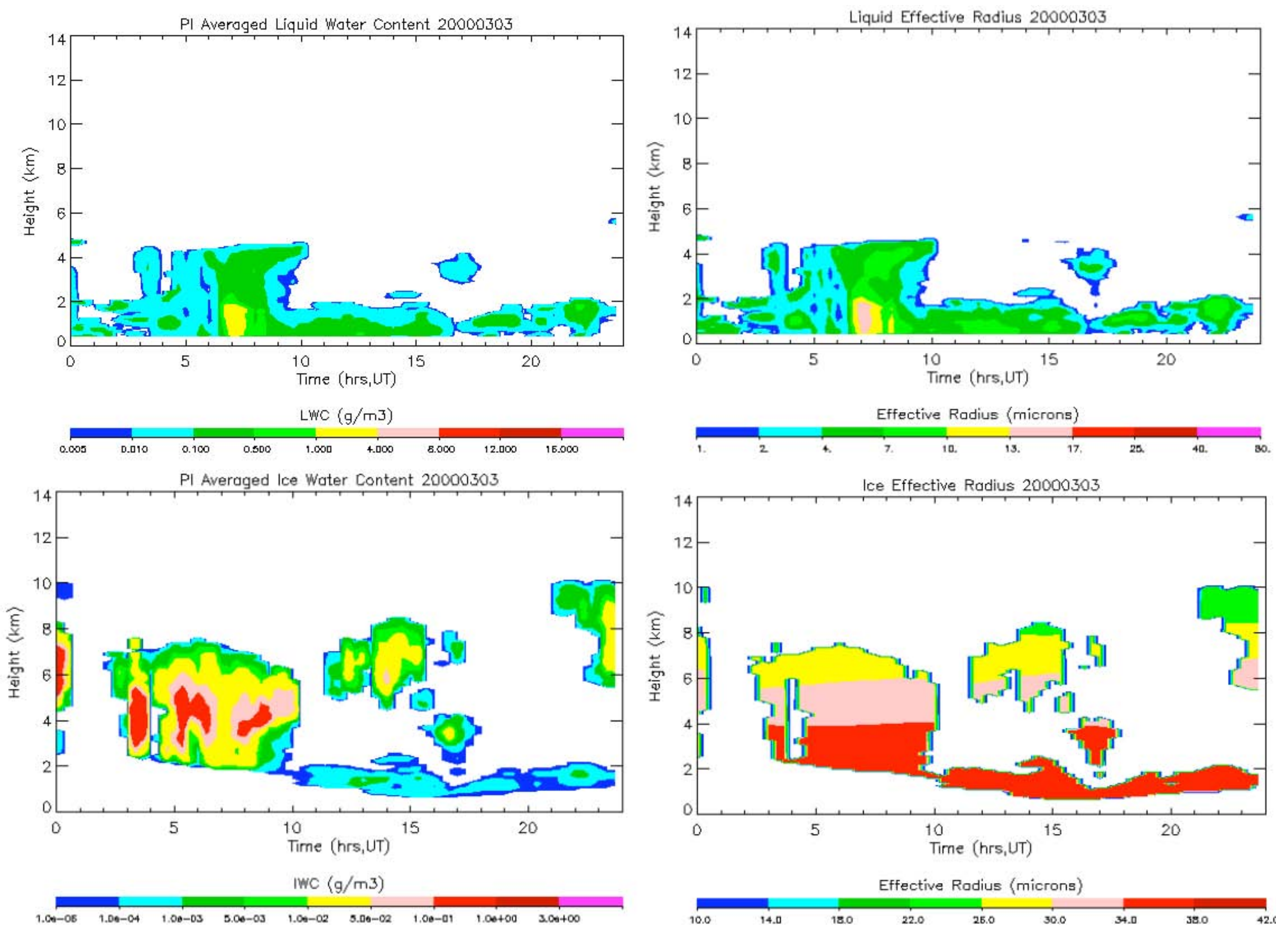

Figure 2. Continuous baseline microphysical retrieval (Microbase) results for the SGPACRF on March 3, 2000: (top left) liquid water concentration (g/m3); (top right) liquid effective radius (mm); (bottom left) ice water concentration (g/m3); (bottom right) ice effective radius (mm).

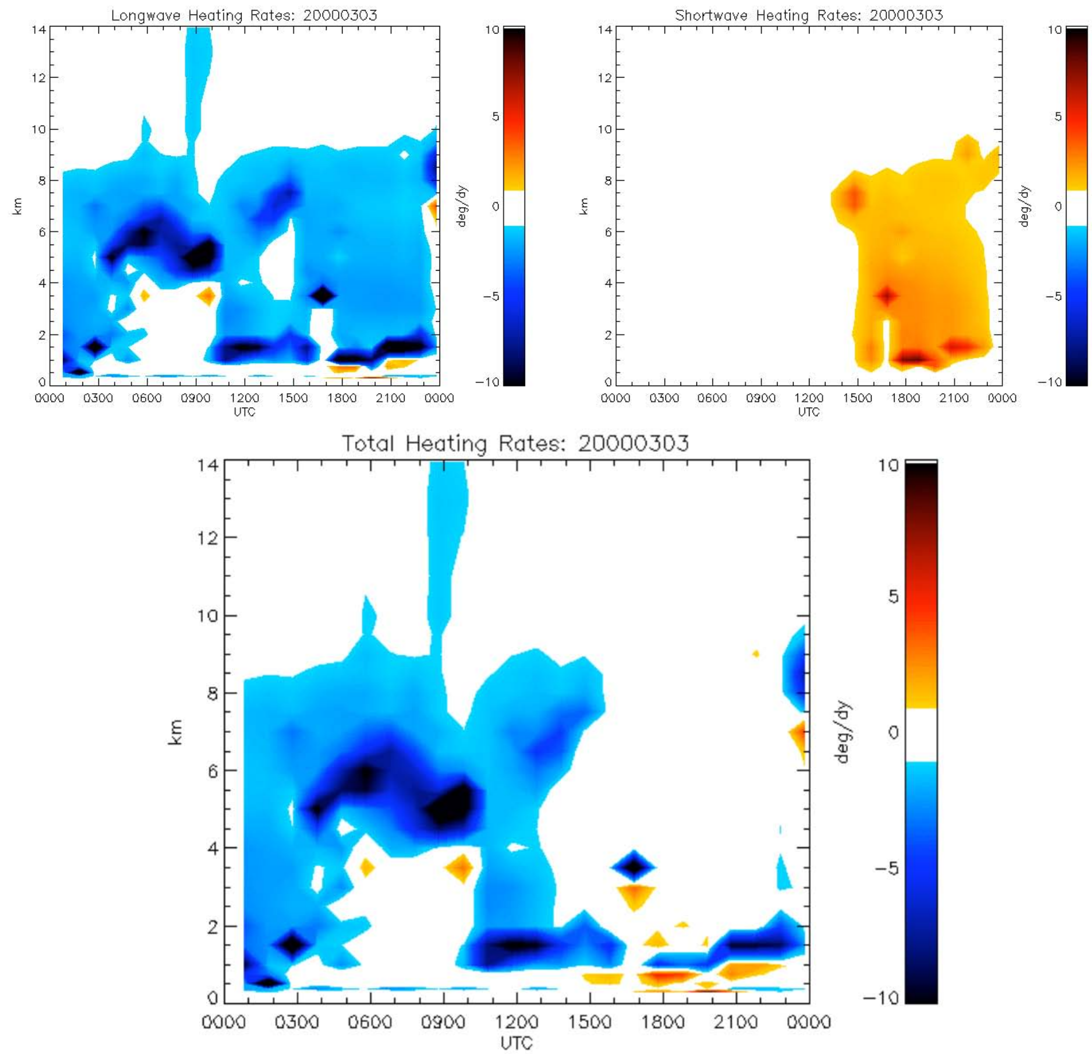

Figure 3. Longwave (top left), shortwave (top right), and total radiative heating rates(K/d) as a function of altitude for March 3, 2000.

4. References

Brown, PD, SA Clough, DD Turner, TR Shippert, RO Knuteson, HE Revercomb, and WL Smith. 1997. "The status of quality measurement experiments in the microwave, longwave, and shortwave." In *Proceedings of the 7th Atmospheric Radiation Measurement (ARM) Science Team Meeting*, San Antonio, Texas, Conference-970365, U.S. Department of Energy.

Clothiaux, EE, TP Ackerman, GG Mace, KP Moran, RT Marchand, M Miller, and BE Martner. 2000. "Objective determination of cloud heights and radar reflectivities using a combination of active remote sensors at the ARM CART sites." *Journal of Applied Meteorology* 39:645-665.

Clough, SA, PD Brown, JC Liljegren, DD Turner, TR Shippert, DC Tobin, HE Revercomb, and RO Knuteson. 1999. "Effect on the calculated spectral surface radiance due to MWR scaling of sonde water vapor profiles." In *Proceedings of the 9th Atmospheric Radiation Measurement (ARM) Science Team Meeting*, San Antonio, Texas.

Fu, Q. 1996. "An accurate parameterization of the solar radiative properties of cirrus clouds for climate models." *Journal of Climate* 9:2058-2082.

Fu, Q, P Yang, and WB Sun. 1998. "An accurate parameterization of the infrared radiative properties of cirrus clouds for climate models." *Journal of Climate* 11:2223-2237.

Hu, YX, and K Stamnes. 1993. "An accurate parameterization of the radiative properties of water clouds suitable for use in climate models." *Journal of Climate* 6:728-742.

Miller, MA and KL Johnson. 2002. "A continuous initial estimate of cloud microphysical structure using surface-based remote sensors and parameterized microphysics." Presented at the 12th Annual Atmospheric Radiation Measurement Program Science Team Meeting, St. Petersburg, Florida.

Mlawer, EJ and SA Clough. 1997. "Shortwave and longwave enhancements in the rapid radiative transfer model." In *Proceedings of the 7th Atmospheric Radiation Measurement (ARM) Science Team Meeting,* San Antonio, Texas, Conf-970365, U.S. Department of Energy.

Mlawer, EJ, SJ Taubman, PD Brown, MJ Iacono, and SA Clough. 1997. "Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave." *Journal of Geophysical Research* 102:16,663-16,682.

Turner, DD, DC Tobin, SA Clough, PD Brown, RG Ellingson, EJ Mlawer, RO Knuteson, HE Revercomb, TR Shippert, WL Smith, and M Shephard. 2004. "The QME AERI LBLRTM: A closure experiment for downwelling high spectral resolution infrared radiance." *Journal of Atmospheric Science* 61:2657-2675.